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MODEL STUDY OF A PROPOSED ENGINEERING ACOUSTIC RESEARCH FACILITY

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MODEL STUDY OF A PROPOSED ENGINEERING ACOUSTIC RESEARCH FACILITY

(ÉTUDE SUR MODÈLE D'UN PROJET D'INSTALLATION DE RECHERCHES EN GÉNIE ACOUSTIQUE)

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SUMMARY

A one-twelfth scale aeroacoustic model of a proposed engineering acoustic research facility has been tested to assess the background noise levels in the anechoic measurement area, and to develop a suitable exhaust collector for deflected jet conditions. The facility comprises an open circuit, open jet wind tunnel with an anechoic space surrounding the test section.

Collector configurations with acceptably low background noise and low sensitivity to jet deflection have been defined, but these features were achieved at the expense of some aerodynamic efficiency.

RÉSUMÉ

On a procédé à l'essai d'un modèle aéroacoustique (échelle 1/12) de l'installation de recherches en génie acoustique projetée en vue d'évaluer les niveaux du bruit de fond dans la salle de mesure anéchoïde et de développer un collecteur d'échappement fonctionnant dans des conditions de jet dévié. L'installation se compose d'une soufflerie à veine libre de type Eiffel et d'un espace anéchoïde entourant la veine.

Les configurations de collecteur ayant un niveau de bruit acceptable et une faible sensibilité à la déviation du jet ont été définies, mais ces dispositifs n'ont été réalisés qu'au détriment du rendement aérodynamique.

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ENGINEERING ACOUSTIC RESEARCH FACILITY

1.0 INTRODUCTION

In September 1971, the Associate Committee on Propulsion sponsored a seminar to discuss a proposed Engineering Acoustic Research Facility for full-scale acoustic studies of moderate sized gas turbine engines, turbomachinery components, and V/STOL high-lift devices, as well as a great variety of non-aeronautical engineering equipment. Because the noise signatures of these engines and high-lift devices are strongly dependent on forward speed, the facility concept allowed for the eventual provision of simulated take-off and landing velocities. Thus, the concept took the form of an open-jet wind tunnel with an anechoic chamber surrounding the test section.

Following this seminar, a Task Force was appointed:

(a) to establish the probable utilization of an acoustic laboratory of the general capabilities outlined in the proposal;

(b) to determine the appropriate physical and acoustical parameters for such a facility; and

(c) to establish the specific steps required to achieve the construction of the facility.

During the evolution of the facility design, concern was expressed within the Task Force about the background noise levels within the anechoic chamber caused by collection of the free jet*, especially when the jet was deflected by the device under test. Accordingly, it was decided that an aeroacoustic model of the fully developed facility should be tested to investigate quiet collector designs. The model work, which was undertaken by the Engine Laboratory, is the subject of this report.

2.0 MODEL DESCRIPTION

A model scale factor of 1/12 was chosen to suit an available 40 horsepower fan. Although a more usual scale factor, in the range of 1/6 to 1/9, would have facilitated acoustic measurements at prototype frequencies above 6 kHz, the smaller scale was preferred for reasons of economy.

In acoustic modelling work of this nature, full-scale velocities must be achieved in the model. The frequency of the noise is thus scaled up by the inverse of the geometric scale factor, and the acoustic power of the noise sources will vary as the square of the linear scale. The sound transmission areas at scaled locations in the model, however, are reduced by the same factor, so that sound intensities in the model will equal those at full scale, provided that the sound absorption characteristics of the model at model frequencies are equal to those in the full-scale facility at prototype frequencies. Since the full-scale facility is to be fully anechoic above 100 Hz, the absorption coefficient of the walls will exceed 99% in the entire high frequency range. This is readily simulated in the model, where the cutoff frequency is 1200 Hz, by means of a flat surface treatment of good quality fibreglass at least two inches thick, and having a density between 3 and 4 lb/ft^3.

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* *The jet referred to throughout this report is the jet of air issuing from the facility nozzle, as distinct from any jet associated with an experiment in the facility working section.*

The facility model was initially installed outdoors in the hope of investigating, among other things, the effects of ambient cross-flow at the inlet. The outdoor tests were, however, plagued with difficulties connected mainly with misalignment and consequent persistent air leaks resulting from weather conditions and the lack of a stable foundation for the model. During these tests, diffusing and fan quieting sections between the facility model and the fan were developed.

Because of the continuing leakage problems, and in anticipation of the onset of winter, the model was rebuilt and relocated indoors. The final test arrangement is shown in Figure 1, and comprised the following main units:

(i) **Intake Bellmouth and Inlet Contraction.** The contraction was designed in accordance with the criteria outlined in Reference 1, and had an area ratio of 6.25 from the termination of the elliptical bellmouth to the nozzle exit. A square cross section with 15% corner fillets was maintained throughout, terminating in a 10 in x 10 in nozzle of the same shape, and having a geometric flow area of 95.5 in^2.

(ii) **Anechoic Test Chamber.** This consisted of a rectangular plywood box stiffened with an external wooden frame and lined with four inches of 3 lb/ft^3 fibreglass. Observation windows and interior lighting were provided in both side walls to facilitate flow observations with wool tufts. The various collector arrangements studied were installed at the downstream end of the chamber.

(iii) **High Velocity Quieting Section.** The collector discharged into a lined length of constant area ducting of 12-inch square internal cross section, in order to re-establish uniform axial flow as soon as possible after the very distorted inflow at the collector inlet during deflected jet conditions. This unit was initially about six feet long with the last two-thirds of the length containing two equally spaced fibreglass-covered vertical splitters to suppress any unstalled or partially stalled diffuser noise that might occur downstream.

(iv) **Diffuser.** A two-dimensional, fibreglass-lined diffuser with an area ratio of 2.25 and included angles of 5° was used to reduce the flow velocity to as low a value as practicable before the fan quieting section. In order to avoid the excessive length required for a more gradual diffuser, a screen was inserted normal to the flow at mid length in order to force the diffuser to run full.

(v) **Fan Quieting Section.** Two additional units were inserted downstream from the diffuser to attenuate the fan noise that propagated upstream to the test section. The first of these was a fibreglass-lined duct containing a vertical splitter, diffusing during the first four feet of its length from 18 inches square to 18 in x 23 in, and remaining parallel at this section for the remaining seven feet. The second unit was a lined plenum chamber with a diagonal baffle.

(vi) **Fan.** The plenum outlet was connected by some 30 feet of unlined 16-in diameter steel ducting and two right-angled elbows to the inlet of a centrifugal fan on the roof of the building. The fan was driven by a 40 horsepower constant speed induction motor and delivered about 1200 ft^3/min at 10 to 12 in H_2O total pressure rise. Discharge was to atmosphere through a lined plywood silencing duct.

3.0 COLLECTOR TESTING AND DEVELOPMENT

3.1 Jet Deflection

The test conditions of interest in the development of a quiet collector involve noise measurements on a V/STOL powerplant or high-lift wing at low forward speeds typical of landing and take-off. Under these conditions, the lift developed by the experiment will deflect the main jet from the axial direction. This was simulated in the facility model by tilting the inlet assembly bodily downwards through angles up to 12 degrees. The deflected jet flow achieved in this way differs in detail from that developed by an immersed high-lift test wing principally as follows.

The test wing will initially deflect the central portion of the total jet flow to an angle rather larger than that used in the simulation, while the remaining flow is deflected by a smaller amount. Further downstream, a more uniform deflection angle will be found in the flow, and finally an inflection point will be reached beyond which the jet deflection decreases as the flow enters the collector. The simulation scheme used here approximates only the latter stage of the real wing-jet deflection flow pattern, from the inflection point downstream.

In the model, the jet deflection occurs further upstream than would be the case with an experimental wing installed in the test section. This causes a greater length of floor within the anechoic chamber to be immersed in the high speed jet, resulting in greater noise radiation; however, it also gives a more gradual inflow to the collector inlet, which has the opposite effect.

The tilting nozzle scheme thus offered an easily repeatable and quiet means of evaluating the collector background noise levels under deflected flow conditions. The alternative would have been to use a scaled high-lift wing in the model test section, presenting great difficulty in producing the required high lift coefficients and introducing an unknown self noise varying with the amount of lift produced.

3.2 Collector Configurations Studied

In a trial-and-error search for the optimum collector, some twenty-one configurations were examined. Full acoustic data were obtained for each of these, and are reported in detail in Reference 5. A brief description of each, along with the "A" weighted sound level at 0°, 6°, and 12° jet deflection, is given in Table 1. The sound levels were measured at the reference microphone location indicated in Figure 1, and are corrected to 150 ft/s nozzle velocity. The datum configuration, Collector No. 1, is shown in Figures 1 and 2. Of the remaining collectors, the better ones, designated Nos. 16, 19, and 20, are sketched in Figures 3, 4, and 5.

3.3 Noise Measurements

Sound level spectra in ⅓ octave bands, along with the linear and A weighted levels, were measured at the reference microphone location for all the collectors studied, generally at deflection angles in 3° increments from 0° to 12°. The A weighted levels only are given for all collectors in Table 1, with the deflection angle increment increased to 6°. The complete spectra are plotted for Collectors 1, 16, 19, and 20 in Figures 2 to 5, which also tabulate four integrated sound levels as follows. The model scale A and linear levels were measured with the conventional A filtering and a flat weighting, respectively. The full scale levels were calculated from the ⅓ octave spectra by applying the conventional A filtering after converting the model frequencies to full scale for the A level, and by arbitrarily discarding all frequencies below the ⅓ octave centred at 1 kHz for the M level. The M level thus corresponds to a full scale linear weighting over the measurable portion of the significant frequency range.

TABLE 1

SUMMARY OF COLLECTORS STUDIED

Collector No.	Free Jet L/D	Area Ratio	Sound Level, dBA 0 °	6 °	12°	Description of Collector
1	4.0	1.44	81.6	89.2	94.1	Datum configuration. Small radius square section bell-mouth. See Fig. 1.
2	4.0	1.44	75.2	76.5	95.3	Large radius square bell-mouth.
3	4.0	3.25	82.3	82.0	82.5	Full height, 5-splitter collector, 50% of area blocked.
4	3.5	1.44	85.1	89.6	93.9	Full height centre body and side baffles.
5	3.5	1.44	82.2	87.2	92.8	Centre body removed; baffles only.
6	3.5	1.44	81.8	87.8	94.0	Edge screening added to baffles.
7	3.2	3.7	79.6	80.7	84.0	12-inch full height vertical slot with baffles and edge screening.
8	3.2	3.7	79.5	80.0	85.1	Edge screening deleted.
9	2.6	3.25	82.3	83.8	82.8	Collector 3 with baffles added.
10	5.4	3.25	82.3	84.8	88.0	Collector 3 moved back flush with rear wall. No baffles.
11	5.4	3.7	79.1	79.9	83.1	Collector 7 with baffles and screening removed.
12	5.4	3.7	78.3	81.3	83.9	Full transverse screen added near throat.
13	3.9	3.7	74.6	75.1	81.6	Collector 11 with large radius entry.
14	3.2	3.7	78.6	80.1	80.6	Collector 13 with baffles added.
15	4.1	5.6	74.7	76.2	77.1	18-inch full height vertical slot with large radius entry. No baffles.
16*	3.4	5.6	80.6	79.8	80.3	Baffles added.
17	4.0	5.6	79.4	80.7	80.2	18-inch vertical slot with short radius entry and baffles.
18	4.0	5.6	75.4	76.4	78.5	Baffle size reduced.
19*	4.0	5.6	74.4	74.6	76.4	Main baffle further reduced. Secondary baffle deleted entirely.
20*	4.7	5.6	74.1	73.5	75.4	Baffles removed.
21	3.5	5.6	80.7	78.5	81.7	Collector 19 with nozzle extended.

* *Quietest collectors*

All sound level data were corrected to a standard nozzle velocity of 150 ft/s by the method described in Section 4.3 below. Because of the short propagation distances and the relatively low frequencies involved in the model study, the molecular attenuation due to atmospheric humidity was judged to be very small, and humidity corrections to the model test results have therefore not been applied.

4.0 SPECIAL STUDIES

A number of special studies that were carried out during the course of the collector development work are described below.

4.1 Effect of Observation Windows

Each of the long sides of the model anechoic chamber was provided with a hard acrylic observation window 1.25 ft^2 in area. Since there was some concern regarding the high frequency absorption of these hard surfaces, a test was run with the windows replaced by fibreglass covered blanks equivalent in sound absorption characteristics to the remainder of the chamber walls. The difference in high frequency absorption was barely detectable at the reference microphone position, and accordingly, no attempt has been made to correct the noise data presented herein for reflection from the windows.

4.2 Low Frequency Overloading of Analyser

Since the one-third octave analyser used for most of the tests had no overload protection or indication, there was some concern that the very large amount of low frequency fan noise that is characteristic of all measured spectra might have overloaded the input amplifier, thus leading to undetected spurious results.

To check this possibility, a test was conducted with a high pass filter having a flat response above 800 Hz inserted between the microphone and the analyser input stage. This effectively blocked the low frequency energy from the amplifier, but no significant differences could be detected between the filtered and the unfiltered spectra above 1 kHz, indicating that the readings were not influenced by overloading.

4.3 Velocity Correction

Because the fan system losses were altered significantly both by the changes in the collector configurations studied and by the nozzle deflection angle, and since the fan speed could not be varied, there were significant jet velocity variations between tests. It was necessary, therefore, to correct all measured noise data to a common nozzle velocity.

Most of the collector noise sources probably vary as the sixth power of velocity, although there may also be some V^8 type noise sources. All measured noise data, both ⅓ octave and weighted overall values, were therefore adjusted to a nominal standard jet velocity of 150 ft/s in accordance with a V^6 intensity dependence. The jet velocity correction is generally less than 15%, giving a correction not more than 4 dB in all bands. The maximum difference between the V^6 and V^8 correction is within the repeatability of the noise data, or about 1 dB. To be rigorously correct, a frequency correction linearly proportional to the jet velocity correction should also be applied, but involves considerable effort, and can be shown to have only higher order effects for broad band noise signatures. This correction has therefore been ignored in the presentation of data.

In order to check the reliability of the V^6 velocity correction, a test was conducted with the fan delivery deliberately restricted, reducing the jet velocity by some 15%. The uncorrected M weighted noise levels with and without the restricted fan exit are plotted against jet deflection angle in Figure 6. The shapes of the curves are quite similar, though displaced as expected. Application of the V^6 velocity correction brings the corrected data into acceptably close agreement, with a maximum discrepancy of 0.75 dB.

4.4 Internal Noise Level Survey

A survey of the sound intensity distribution in the anechoic volume was carried out with collector No. 17 for nozzle deflection angles of 0° and 12°. Six microphone positions, all in the horizontal plane of the centre line of the undeflected jet, were used in addition to the reference position. These are shown in Figures 7 and 8, which also give the ⅓ octave noise spectrum and the weighted sound levels for microphone position and deflection angle. At 12° jet deflection on the open side of the jet, the sound absorption of the baffles is evident, since the levels at both downstream stations D and B are lower than the corresponding levels at stations A and C. For the undeflected jet this effect did not appear. Generally, the A levels r ured two jet diameters (20 in) from the axis are 2 to 3 dB above those measured at 3 diameters from the axis. The sound level variation parallel to the jet axis, as a function of jet deflection angle, is smaller and more erratic than that perpendicular to the axis. On lines parallel to the jet axis two competing effects are probably involved in establishing the observed background levels. Moving in the downstream direction, levels would tend to rise as the collector noise source separation distance is reduced; simultaneously, however, the noise suppression due to the baffle will improve. For the deflected jet the important jet noise sources will occur near the model floor at the downstream wall of the chamber. The spectra at the microphone positions close to the rear wall show a somewhat increased level of low frequency noise (below 1 kHz), which is not included in the M weighted level.

Sound levels were measured even closer to the jet axis on the opposite side of the jet at locations E and F, and the sound levels are seen to be much higher. At zero deflection, the considerable aerodynamic impingement noise at location F. This is improved somewhat a deflection because of the improved clearance above the jet. It is not expected, however, that us noise measurements can be made in such close proximity to the jet.

4.5 Rod Radiation Study

As a simple test to illustrate a typical noise spectrum achievable with this facility, a full height, ¼ inch diameter rod was installed vertically on the jet centre line at the downstream end of the test section. This is indicated in Figure 9, which also gives the ⅓ octave spectra measured at 0°, 6°, and 12° jet deflection. These may be compared with the spectra for the undisturbed jet and the same collector (No. 19) given in Figure 4. The following noise radiation phenomena are indicated.

(i) The primary Strouhal peak (oscillating lift source) is clearly evident. The derived Strouhal number, 0.18, is in excellent agreement with other rod data. The power radiated by the ¼ inch rod is seen to be adequate to generate levels 25 dB above the background level of the tunnel.

(ii) The shift of the Strouhal peak to a lower frequency as the jet inclination is increased to 12° reflects the reduction in the cylinder cross flow velocity component with the yawed flow. The cosine dependence is shown by the much greater frequency shift between 6° and 12° than between 0° and 6°.

(iii) The overall sound power radiated decreases noticably at 12° jet deflection, reflecting the considerable reduction in cylinder area exposed to the jet when the jet flow intersects the floor.

(iv) The presence of a second radiation peak at twice the fundamental Strouhal frequency is attributable to the oscillating drag force on the cylinder. The oscillating lift and oscillating drag forces on the model will have quite different noise radiation directivity patterns. At the reference microphone location, both fields may be detected; moving closer to the jet axis will substantially augment the relative contribution from the drag forces at the second harmonic of the Strouhal frequency.

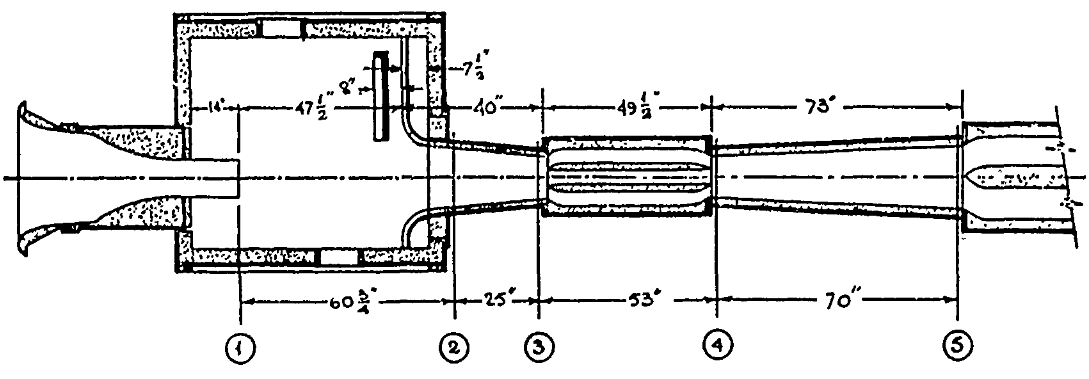
4.6 High Frequency Test

Some additional tests were carried out with the last collector studied (No. 21) to check for the possibility of peaks in the spectra beyond the frequency range covered by the bulk of the tests. A high frequency measuring amplifier (Brüel & Kjaer Model 2604) and a ⅓ octave filter set (B & K Model 1614), extending the measuring range to 160 kHz, were used in place of the low frequency analysers (B & K model 2109, and later 2203) used for the earlier studies. Both a ¼ and a ⅛ inch condenser microphone were used for the high frequency runs.

Data obtained with the ⅛ inch microphone indicated that, for this collector configuration, a small, smooth increase of 3 to 4 dB occurs in the 40 to 50 kHz region, followed by a slow decrease extending to at least 100 kHz. A portion of this increase may be attributable to the microphone response characteristics.

On the basis of the high frequency measurements conducted, it is clear that no undesirable high frequency contributions exist in the final collector geometries. The energy spectrum remains essentially flat out to at least 125 kHz, corresponding to 10 kHz at full scale.

4.7 Collector Flow Loss Measurements



Station 1	–	Nozzle exit	–	95.5 in² flow area
Station 2	–	Within the collector	–	505 in² flow area
Station 3	–	Collector exit	–	154 in² flow area
Station 4	–	Diffuser inlet	–	144 in² flow area
Station 5	–	Diffuser exit	–	324 in² flow area

TABLE 2

PRESSURE SURVEY

Pressures in inches of water referenced to atmospheric pressure

Station No.	Jet Deflection Angle	Static Pressure	Total Pressure
1	0°	-6.95	-0.12
2	0°	-6.40	-5.11
	6°	-6.50	-5.43
	12°	-6.55	-5.97
3	0°	-6.85	-4.10
	6°	-6.90	-4.14
	12°	-7.00	-4.24
4	0°	-9.10	-5.16
	6°	-9.40	-5.65
	12°	-9.90	-6.09
5	0°	-8.00	-7.12
	6°	-8.40	-7.50
	12°	-8.10	-7.29

Static and total pressure measurements were carried out with Collector 21 in order to establish the pressure recovery of the jet collection system. Wall static pressures were measured and total pressure surveys carried out across the horizontal and vertical centre lines at the following stations as indicated in the sketch above.

The static and area-averaged total pressures, referenced to atmospheric pressure, are given in Table 2, and total pressure profiles for the more significant cases are presented in Figures 10 to 13. The following points are of special interest.

(i) At the 0° setting of the jet nozzle, there remains a noticeable downward deflection of the jet at the collector. The spuriously low area-averaged total pressures reported for Station 2 may be explained by flow reversals observed near the collector walls, and particularly in the corners. Pressures measured at this station are of value only as a qualitative indication of flow distribution.

(ii) The undeflected jet is reasonably well collected at the collector exit, Station 3.

(iii) Significant frictional flow losses are introduced by the vertical splitters in the parallel section between the collector and the diffuser.

(iv) The jet is seriously constrained by the floor at the higher jet deflections. At 12° deflection the maximum jet velocity in the collector occurs at a position only 4% of the channel height above the floor, compared with 16% at 6° deflection.

To assess the pressure loss at 0° jet deflection, it is assumed that the jet collection process is complete at Station 3; it is clear from Figures 10 to 13 that the free jet persists at Station 2. The total pressure loss along the free jet and collector, then, is the area averaged value of the quantity

$$(P_{T1} - P_{TA}) - (P_{T3} - P_{TA}) \tag{1}$$

where $(P_{T1} - P_{TA})$ and $(P_{T3} - P_{TA})$ are the total pressures (referenced to atmospheric pressure) at nozzle and collector exits respectively. This pressure loss value is conveniently non-dimensionalized by the jet dynamic pressure at Station 1, the jet exit, so that one can define

$$K_{13} \equiv \frac{\Delta P_{T_{13}}}{q_1} = \frac{3.98'' \; H_2O}{3.83'' \; H_2O} = 0.58 \qquad \text{for the undeflected case}$$

where K_{13} is the measured pressure loss for the free jet and collector.

Various authors (References 2, 3, and 4) give loss coefficients for collected open jets (at 0° deflection) in the range

$$0.80 \, (\ell/d)_j \leqslant K_{jc} \leqslant 0.092 \, (\ell/d)_j \tag{2}$$

where K_{jc} is the loss coefficient for the free jet and collector and $(\ell/d)_j$ is the length to diameter ratio of the free jet.

In the present case, the undeflected free jet persisted some distance into the collector, as shown in Figure 12, since, in order to cope with the deflected jet, the collector entry had to be considerably larger than necessary in the undeflected condition. This situation is commonly referred to as "overcollection". The appropriate free jet length to be used in conjunction with relationship (2) was therefore arbitrarily judged to be about 55 inches (see sketch on page 15), giving a $(\ell/d)_j$ of 5.0 for the effective nozzle diameter of 11 inches.

From relationship (2) then, the expected free jet loss coefficient, without overcollection, for the undeflected case would be

$$0.40 \leqslant K_{jc} \leqslant 0.46 \tag{3}$$

These values are seen to be 20% to 30% below the measured pressure loss coefficient (0.58) for the undeflected free jet and collector of the acoustic facility model. The additional loss in the specialized collector may be accounted for by wall friction in the downstream portion of the collector between the arbitrarily defined termination of the free jet and Station 3, the collector exit. In the collector designed for operation with a deflected jet, one may distinguish two types of flow loss that do not occur in a conventional collector designed to handle only the undeflected jet case:

(i) The free jet extends well into the collector, the stagnation point in the impinging collector flow occurring well downstream from the collector inlet. This implies that, for a given test section length, increased mixing losses are incurred because of overcollection.

(ii) A greater wall loss is to be expected within the collector itself in returning the flow to an area only 60% greater than the nozzle exit, again because of overcollection.

The significance of these increased jet and collector pressure losses in terms of the total power required by the full scale facility can also be assessed in terms of the pressure loss coefficients. If one compares two tunnel circuits with the same jet velocity and area, the ratio of the power required will be the same as the ratio of the total circuit pressure loss coefficients. The cost, in terms of installed power, of the special collector capable of quietly swallowing the deflected jet can therefore be evaluated in comparison with a conventional undeflected open jet collector circuit.

A typical total circuit loss factor for a conventional open jet tunnel with a free jet length to diameter ratio of 3 is given by References 3 and 4 as

$$0.40 \leqslant \frac{\Delta P_{circuit}}{q_{jet}} = K_{circuit} \leqslant 0.50 \tag{4}$$

of which the contribution of the jet and collector (from relationship (2), at $(\ell/d)_j = 3.0$) would be

$$0.24 \leqslant \frac{\Delta P_{jc}}{q_j} = K_{jc} \leqslant 0.28$$

Assuming no change in the other circuit components, one can calculate the total circuit loss factor of a conventional undeflected open jet tunnel with a jet length to diameter ratio of 4.3 (i.e. the same as that of the proposed facility) to be

$$0.47 \leqslant \frac{\Delta P_{circuit}}{q_{jet}} = K_{circuit} \leqslant 0.66 \tag{5}$$

The corresponding value for the quiet circuit can be obtained by adding the measured jet and collector loss factor (0.58) to the loss factor for the other circuit elements, which is assumed to be the same for the two circuits. This gives

$$0.69 \leqslant \frac{\Delta P_{circuit}}{q_{jet}} = K_{circuit} \leqslant 0.83 \tag{6}$$

Comparing average values in Relationships (6), (5), and (4), it can be seen that the total power required for the quiet circuit is about 35% more than that for a conventional circuit with the same jet length to diameter ratio (4.3), or 71% more than that for a conventional circuit with a more usual jet length to diameter ratio of 3.

Similarly, the data given above may be used to determine the additional losses associated with the deflected jet. The average values of these additional losses, for both deflected and undeflected conditions, are summarized below.

TABLE 3

AVERAGE VALUES OF ADDITIONAL LOSSES

	ℓ/d	Jet Deflection Angle	Average K circuit	Percentage Loss cf(a)	cf(b)
Conventional (a)	3	0°	0.45	0	-
Conventional (b)	4.3	0°	0.57	27	0
Quiet	4.3	0°	0.77	71	35
Quiet	4.3	6°	0.81	80	42
Quiet	4.3	12°	0.83	84	46

The increment in total aerodynamic power with the quiet collector is seen to be sizeable, reflecting the fact that the jet collection loss represents the major circuit loss, even with the more efficient conventional collector configurations. One would expect the total circuit pressure loss factor of a typical open jet circuit including the collector scheme developed above to be approximately 0.75, corresponding to an energy ratio of 1/0.75 = 1.33.

The installed power required for the full scale facility with 12° jet deflection and the quiet collector as developed here would likely be about 600 horsepower, i.e. about 270 horsepower more than that required for a conventional open jet wind tunnel of the same size with an undeflected jet and a length to diameter ratio of 3 for the jet.

5.0 DISCUSSION OF RESULTS

Examination of Table 1 discloses a general improvement in background noise throughout the collector development program up to Collector 19, after which no further beneficial changes were made. The detailed test results, reported in Reference 5, confirm that No. 19 was, indeed, the best of the collectors tested, and achieved the following levels at the reference microphone location.

Deflection angle	0°	6°	12°
M weighted level	61.0 dB	60.6 dB	61.4 dB
A weighted level at model scale	74.4 dB	74.6 dB	76.4 dB
A weighted level at full scale	57.8 dB	57.7 dB	58.3 dB

These match the desired background noise requirements as set out in Appendix A, but are still significantly above the absolute floor level set by the free mixing quadrupole noise sources in the free jet, as derived in Appendix B.

Some optimization of the acoustic baffles was involved in the development of this collector, resulting in the complete removal of the short baffle on the one side of the air stream and a 2-inch reduction from the inside edge of the larger baffle, leaving a 22-inch opening to provide the necessary clearance for the jet and its entrained flow. It has been observed that the primary effect of the baffles on the noise level measured at the reference microphone location is a slight reduction at frequencies above 2 kHz. Their effect on the M and model scale A weighted levels is thus minimal, but the full scale A weighted level is improved by 2 to 3 dB. It was also observed in some of the early tests with

and without baffles that a substantial amount of low frequency noise was actually being generated by the motion of the panels, thus stressing the need for rigid mounting.

It is clear that for quiet collection of the deflected jet, a large collector entrance area with well radiused inlet contours is required. The penalty for this is reduced aerodynamic efficiency, as evidenced by a drop of about ten percent in the test section velocity when comparing the early collectors with the later, quieter configurations at the same fan speed.

6.0 ADDITIONAL WORK INDICATED

An important objective of the present program was the determination of the effects of ambient cross flow on the uniformity of flow and the tubulence levels in the test section. With the relocation of the test work indoors, the possibility of using natural wind conditions was removed. It would still be possible, however, to duplicate the natural cross flow conditions artificially in the indoor location. This phase of the program still remains incomplete.

A second important area for further work is the optimization of that part of the model between the collector and the fan. At present, this section includes a high velocity quieting and flow straightening section, a lined diffuser, and a low speed fan quieting section. The present component arrangement was intended to adapt simply to the existing fan unit rather than to provide the maximum total pressure recovery downstream of the collector. A much more efficient arrangement would eliminate the high velocity flow straightening section completely if possible, and relocate the diffuser immediately downstream from the collector. Alternatively, the flow straightening and diffusing sections might be combined into a single section immediately downstream from the collector exit. Any additional fan quieting sections are most efficiently located downstream from the final diffuser.

Additional analytical and experimental studies covering alternative component arrangments are well warranted, since significant power savings and trade-offs between first and operating costs are possible.

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5. Johnston, G.W.; Rueter, F.; Chappell, M.S. — Model Study of a Proposed Engineering Acoustic Research Facility: Detailed Test Results. N.R.C. D.M.E. Laboratory Technical Report LTR-ENG-46. National Research Council of Canada, Ottawa, Canada, September 1975.

FIG. 1

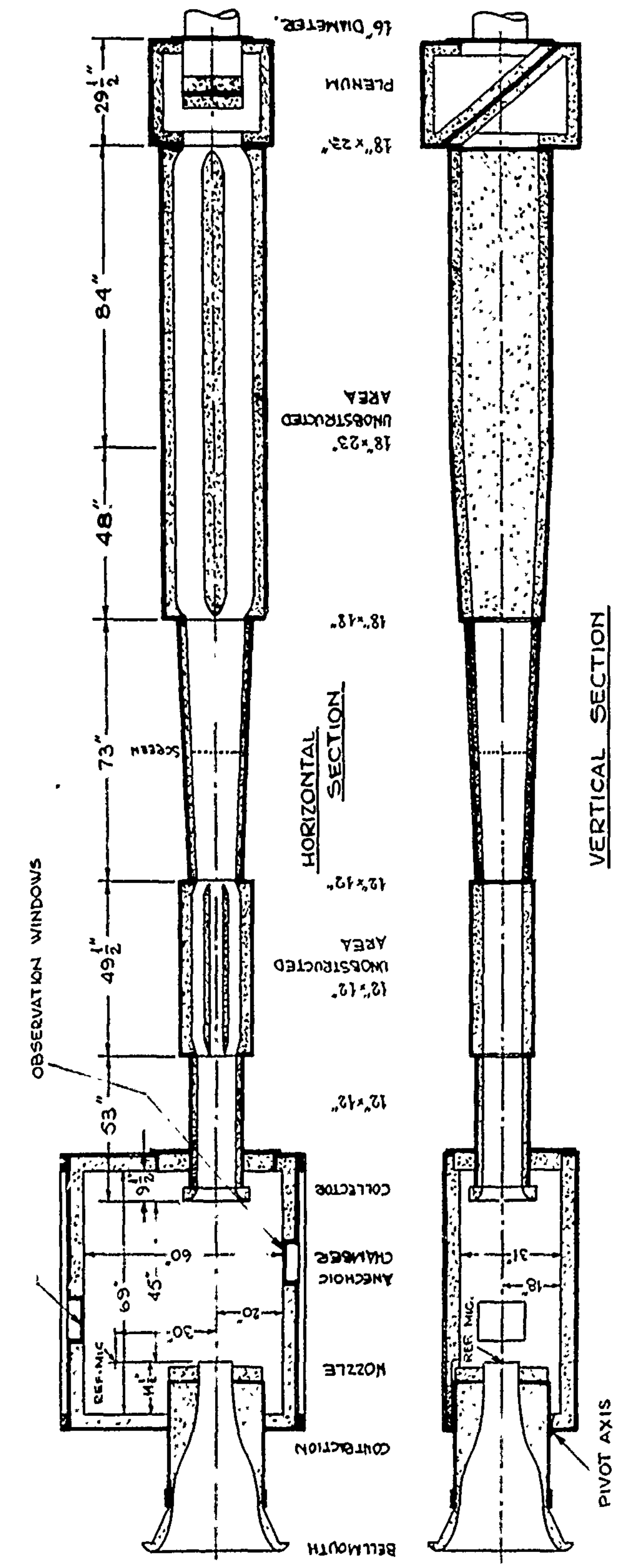
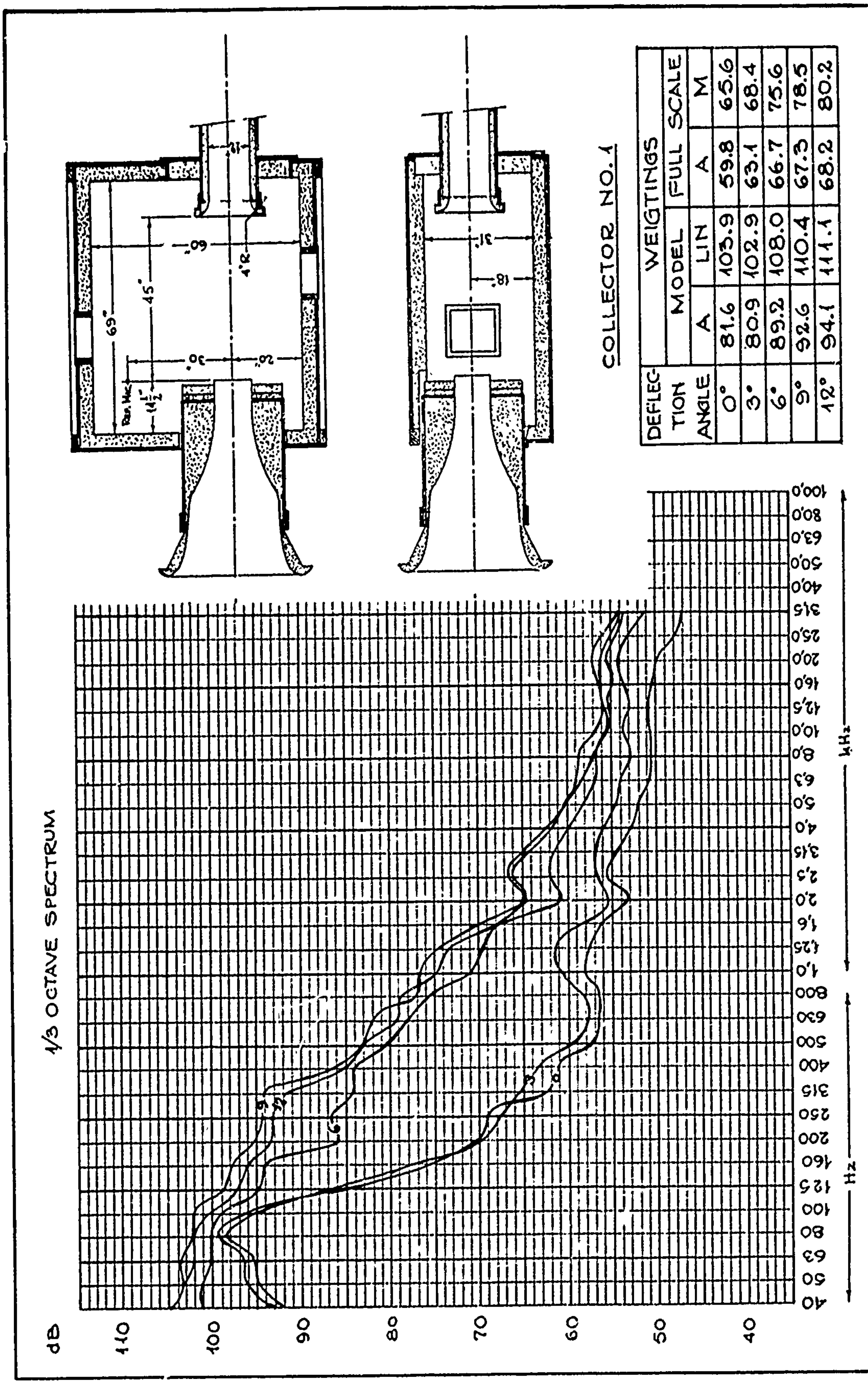


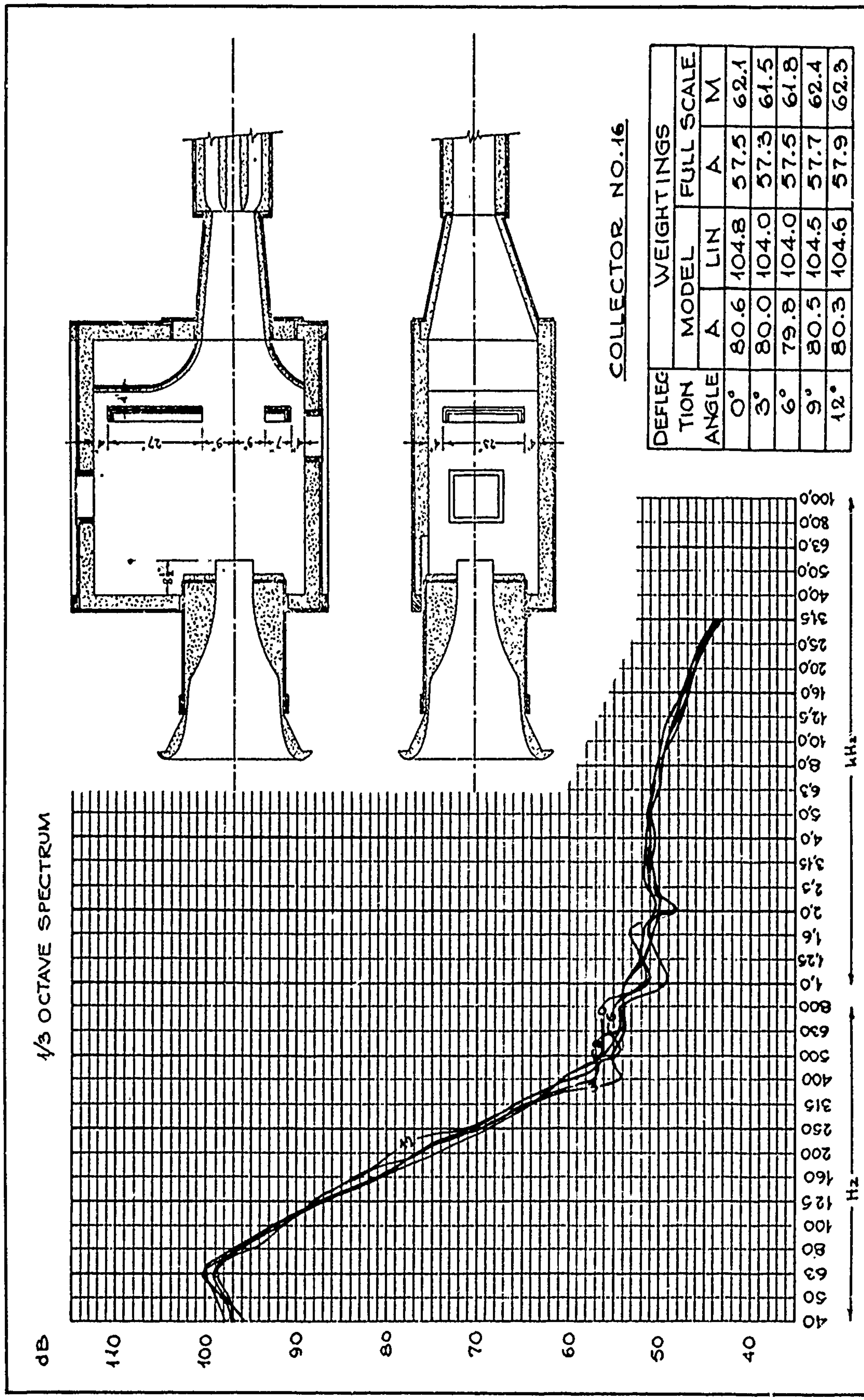
FIG. 1
ACOUSTIC RESEARCH FACILITY MODEL
MODEL SCALE : 1/12

FIG. 2



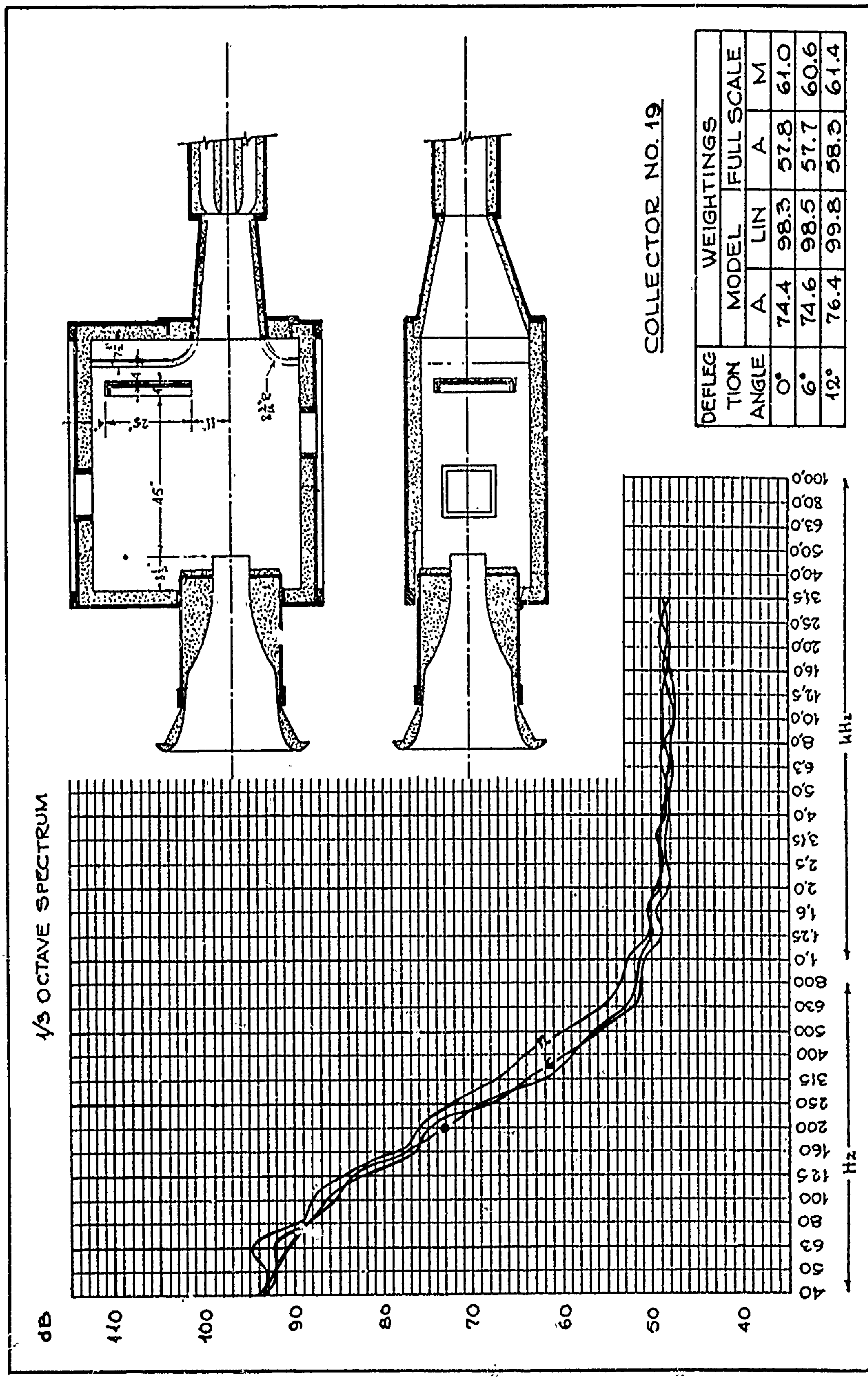
DEFLECTION ANGLE	WEIGTINGS MODEL A	WEIGTINGS MODEL LIN	FULL SCALE A	FULL SCALE M
0°	81.6	103.9	59.8	65.6
3°	80.9	102.9	63.1	68.4
6°	89.2	108.0	66.7	75.6
9°	92.6	110.4	67.3	78.5
12°	94.1	111.1	68.2	80.2

FIG. 3



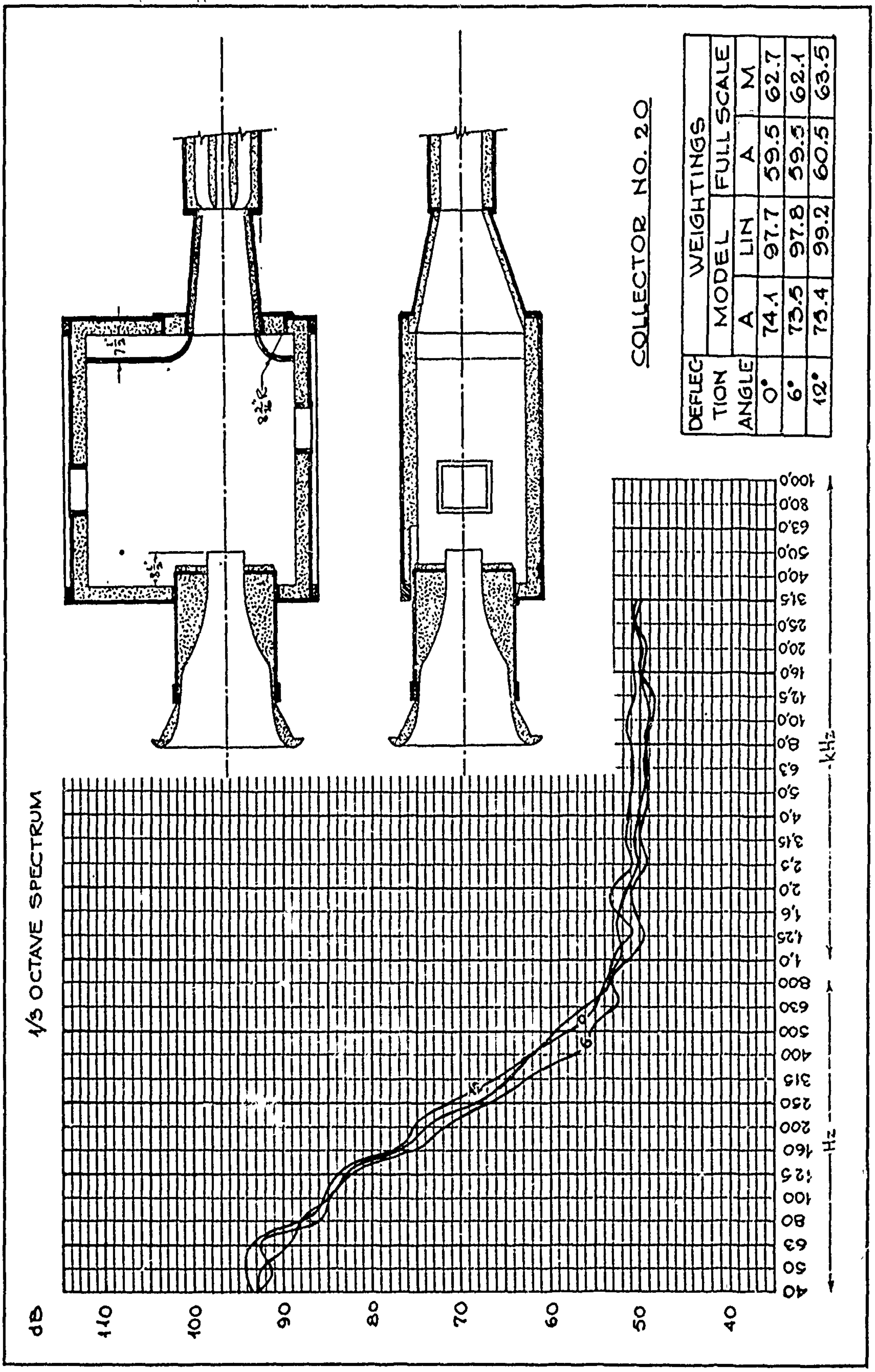
DEFLEC TION ANGLE	WEIGHTINGS			
	MODEL		FULL SCALE	
	A	LIN	A	M
0°	80.6	104.8	57.5	62.1
3°	80.0	104.0	57.3	61.5
6°	79.8	104.0	57.5	61.8
9°	80.5	104.5	57.7	62.4
12°	80.3	104.6	57.9	62.3

FIG. 4



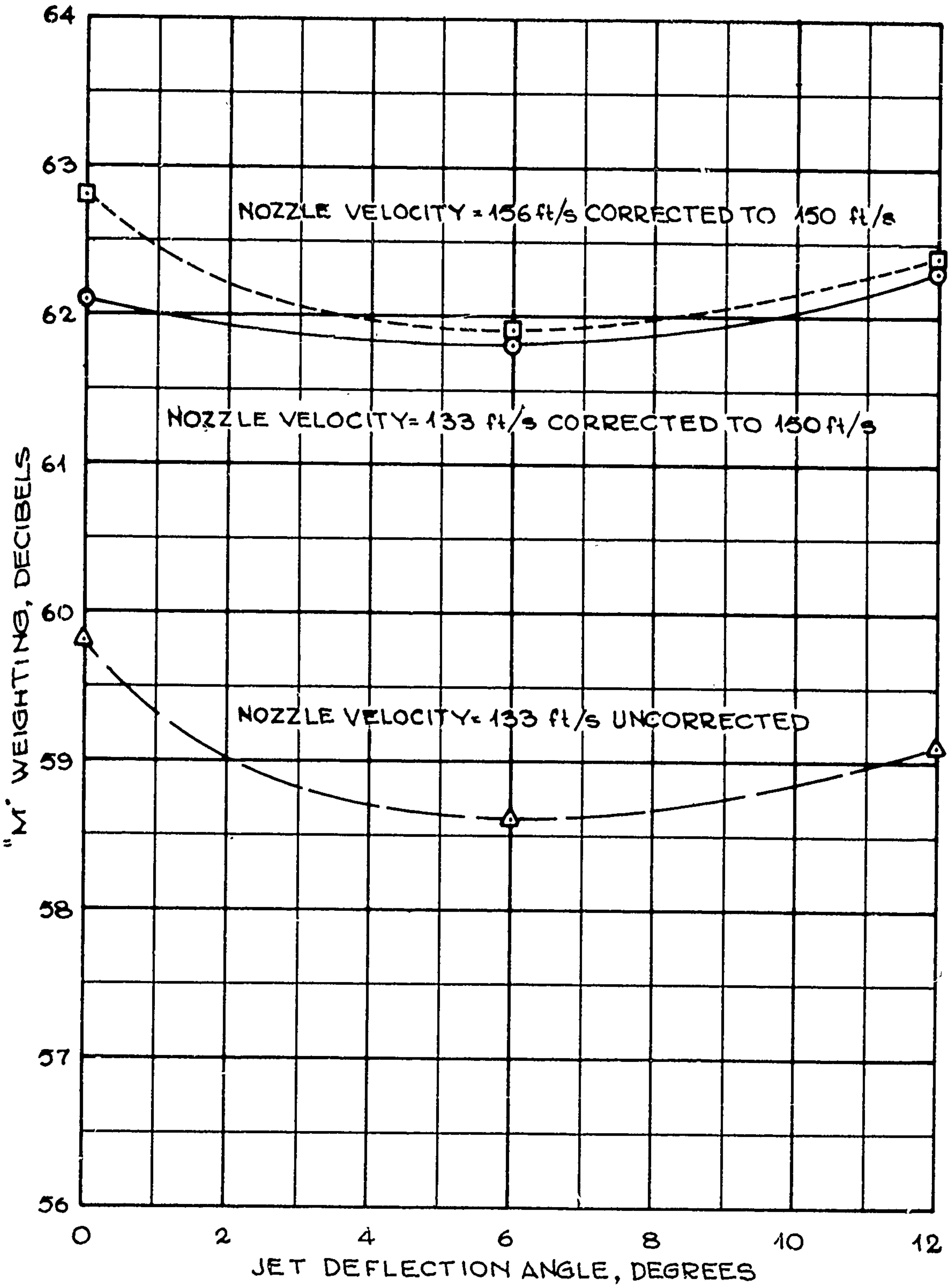
DEFLECTION ANGLE	WEIGHTINGS MODEL A	LIN	FULL SCALE A	M
0°	74.4	98.3	57.8	61.0
6°	74.6	98.5	57.7	60.6
12°	76.4	99.8	58.3	61.4

FIG. 5



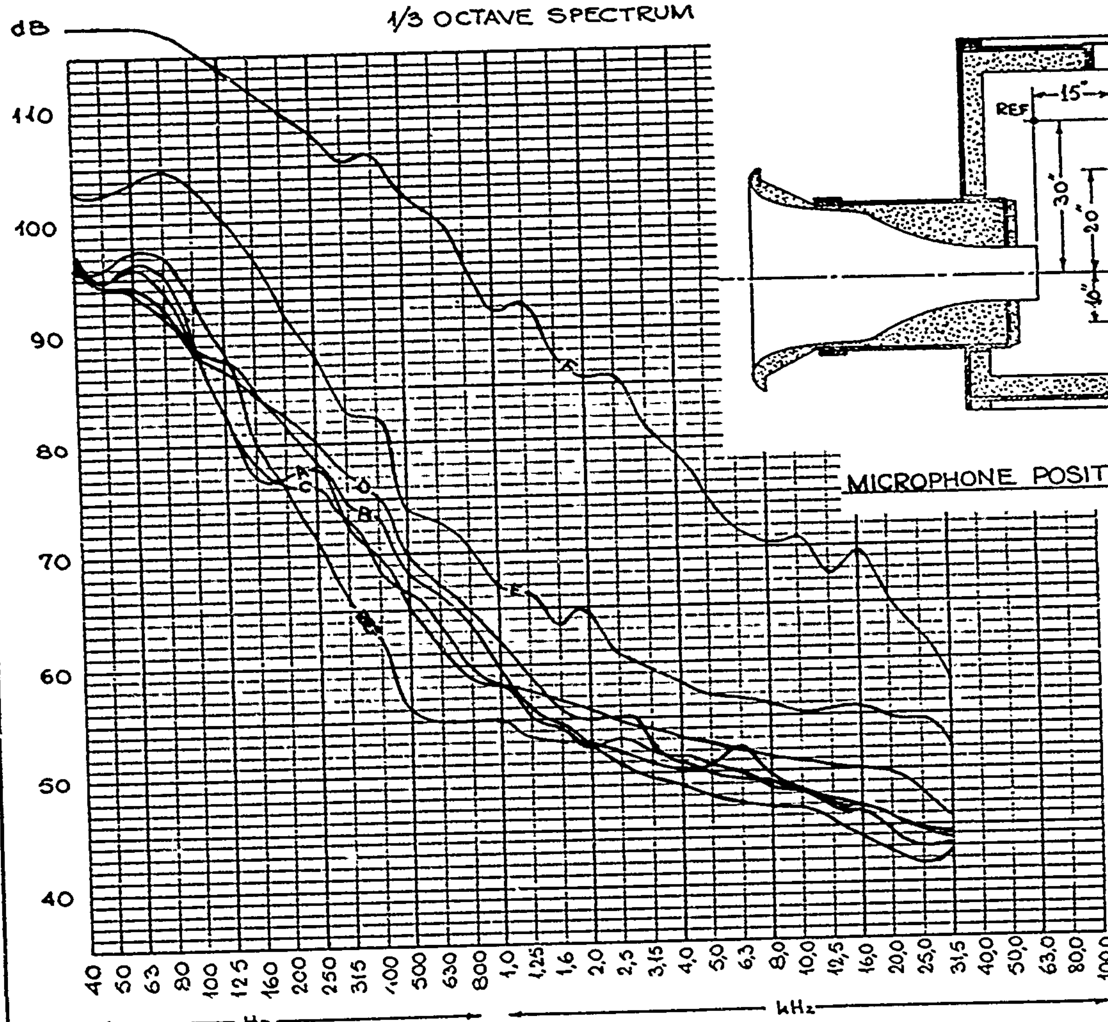
DEFLECTION ANGLE	WEIGHTINGS MODEL A	WEIGHTINGS MODEL LIN	FULL SCALE A	FULL SCALE M
0°	74.1	97.7	59.5	62.7
6°	73.5	97.8	59.5	62.1
12°	73.4	99.2	60.5	63.5

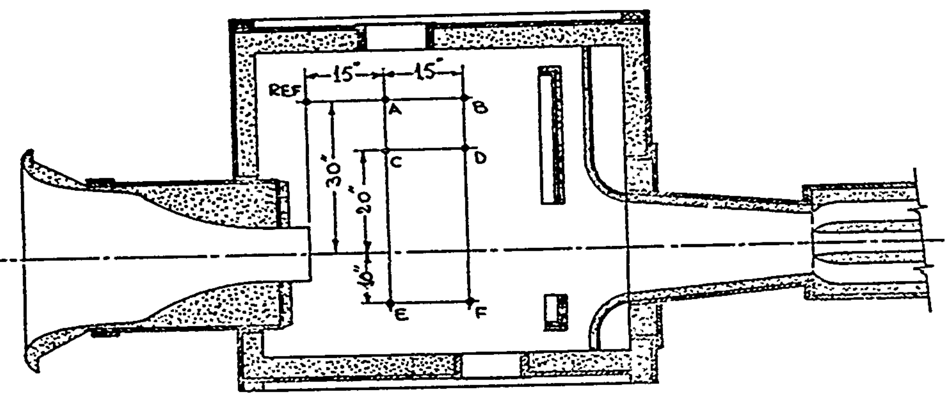
FIG. 6



VELOCITY CORRECTION TEST

FIG. 7



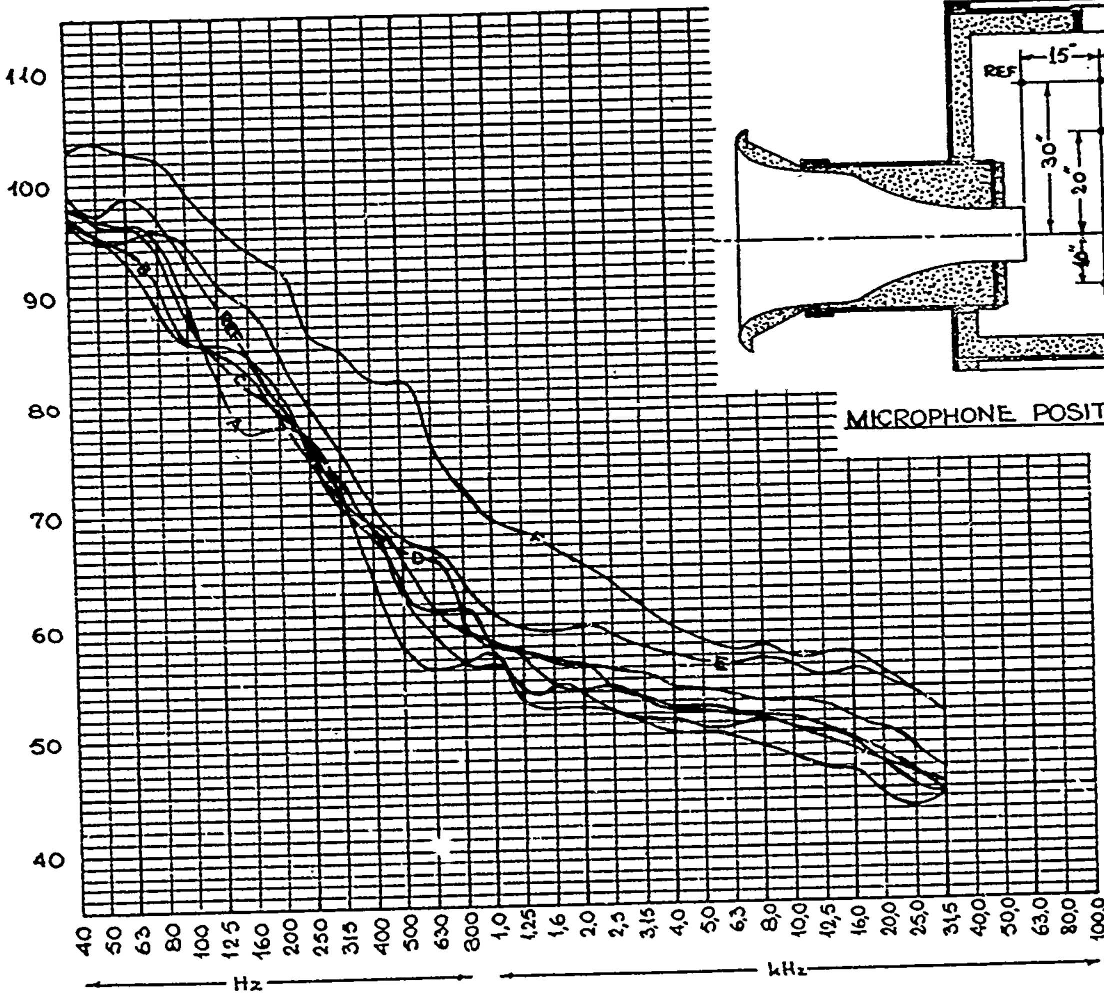


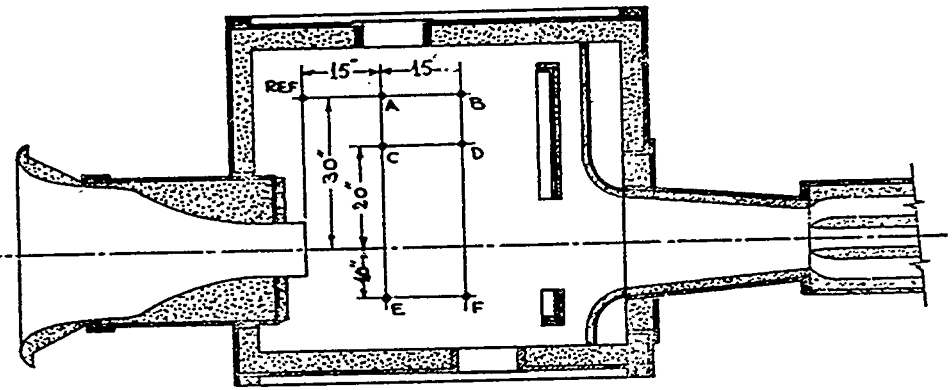
MICROPHONE POSITIONS FOR NOISE SURVEY

COLLECTOR NO. 17
NOISE SURVEY AT 0° JET DEFLECTION

MICRO-PHONE POSITION	WEIGHTINGS			
	MODEL		FULL SCALE	
	A	LIN	A	M
REF	80.1	103.3	57.6	63.0
A	78.5	101.7	56.8	63.9
B	80.2	101.5	55.3	63.8
C	79.0	102.6	59.9	65.9
D	80.8	101.0	57.6	66.4
E	91.4	111.2	65.3	72.9
F	109.3	125.3	83.2	96.8

FIG. 8





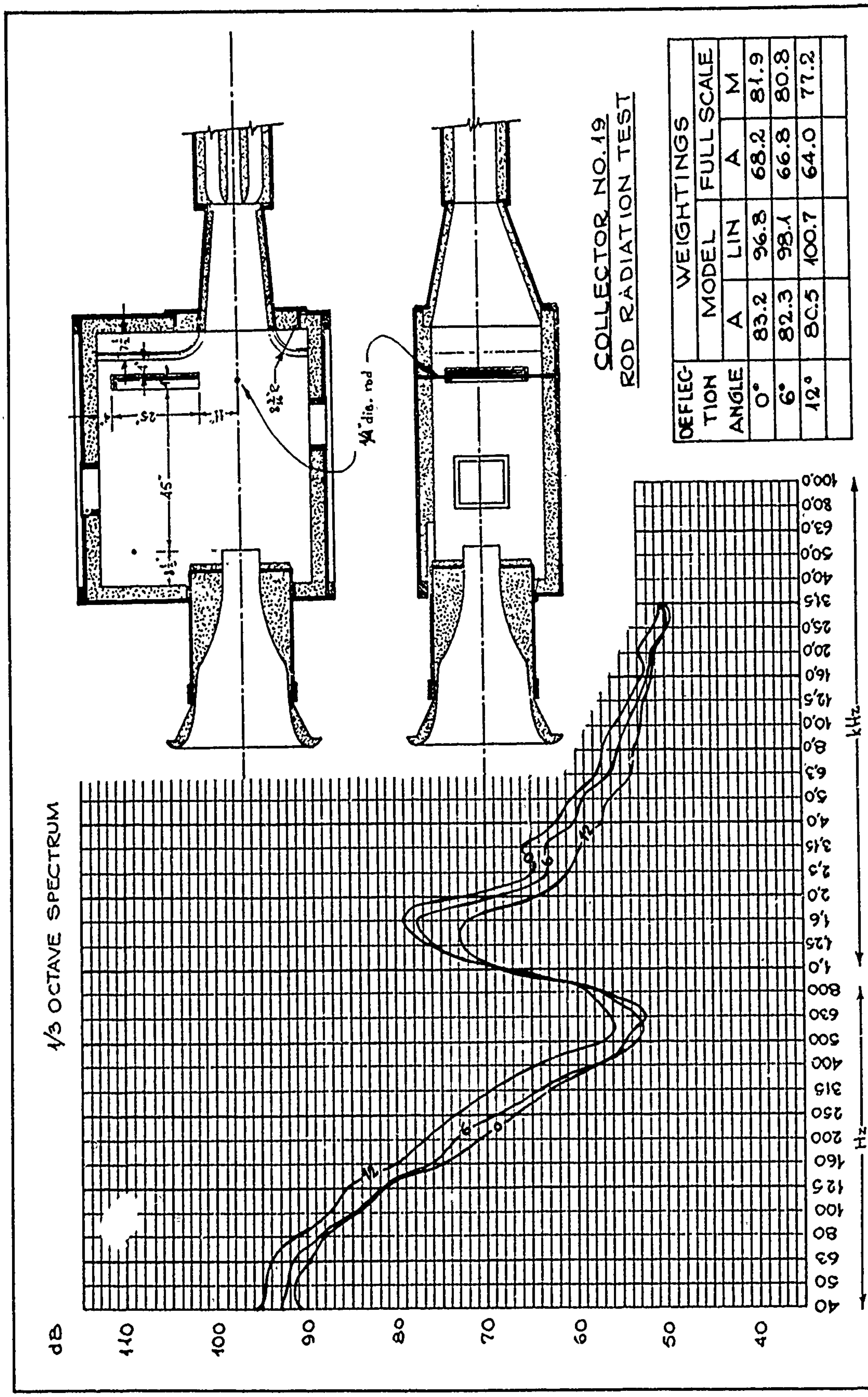
MICROPHONE POSITIONS FOR NOISE SURVEY

COLLECTOR NO. 17

NOISE SURVEY AT 12° JET DEFLECTION

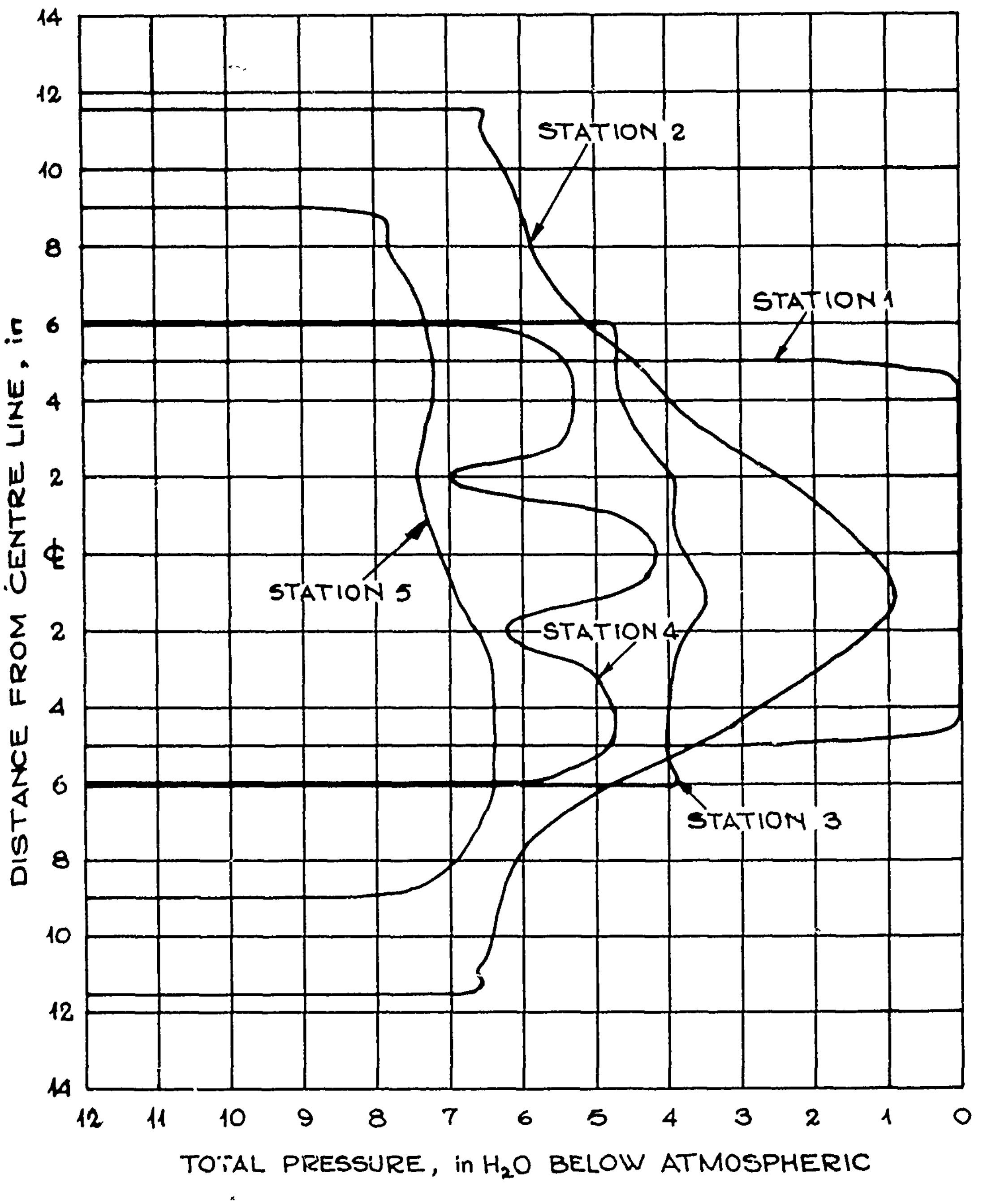
MICRO-PHONE POSITION	WEIGHTINGS			
	MODEL		FULL SCALE	
	A	LIN	A	M
REF	81.4	104.7	58.6	63.5
A	78.7	103.5	58.9	64.7
B	78.3	101.1	56.9	63.5
C	79.0	102.8	61.2	66.5
D	77.7	100.7	59.6	65.5
E	82.9	102.8	64.8	69.5
F	90.0	110.0	66.5	75.1

FIG. 9



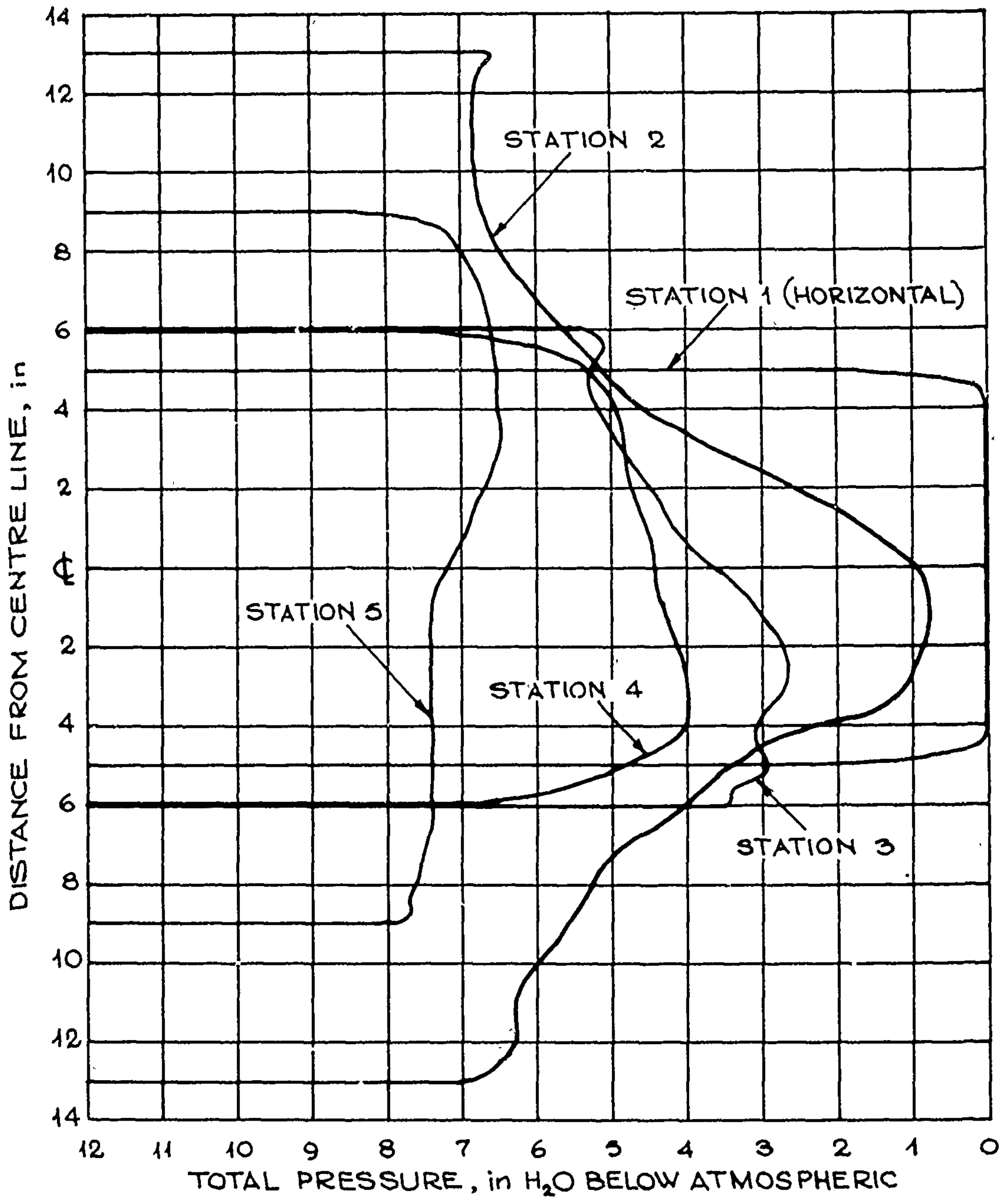
DEFLEC-TION ANGLE	WEIGHTINGS MODEL A	MODEL LIN	FULL SCALE A	FULL SCALE M
0°	83.2	96.8	68.2	81.9
6°	82.3	98.1	66.8	80.8
12°	80.5	100.7	64.0	77.2

FIG. 10



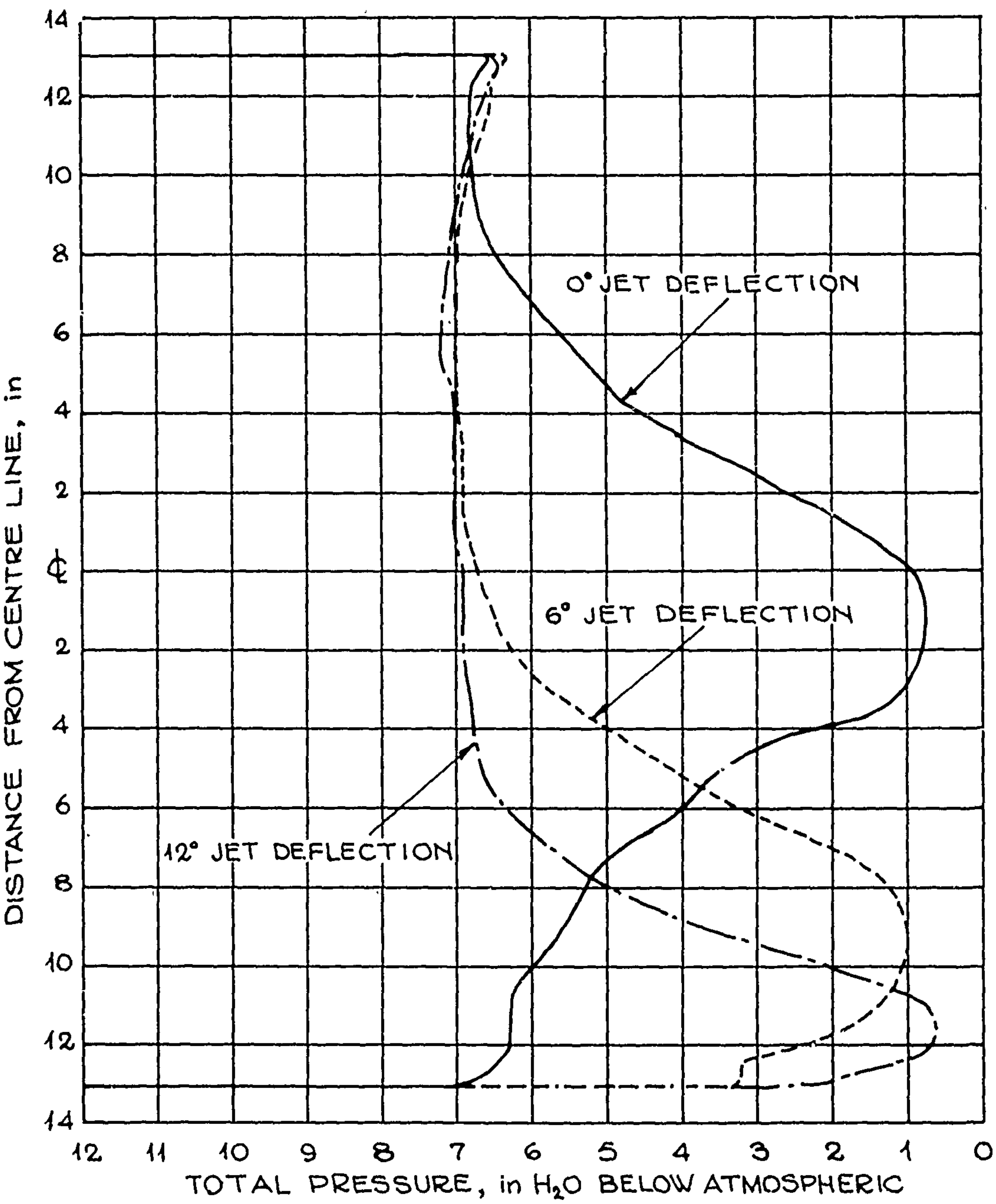
HORIZONTAL TRAVERSES AT 0° JET DEFLECTION
COLLECTOR NO. 21

FIG. 11



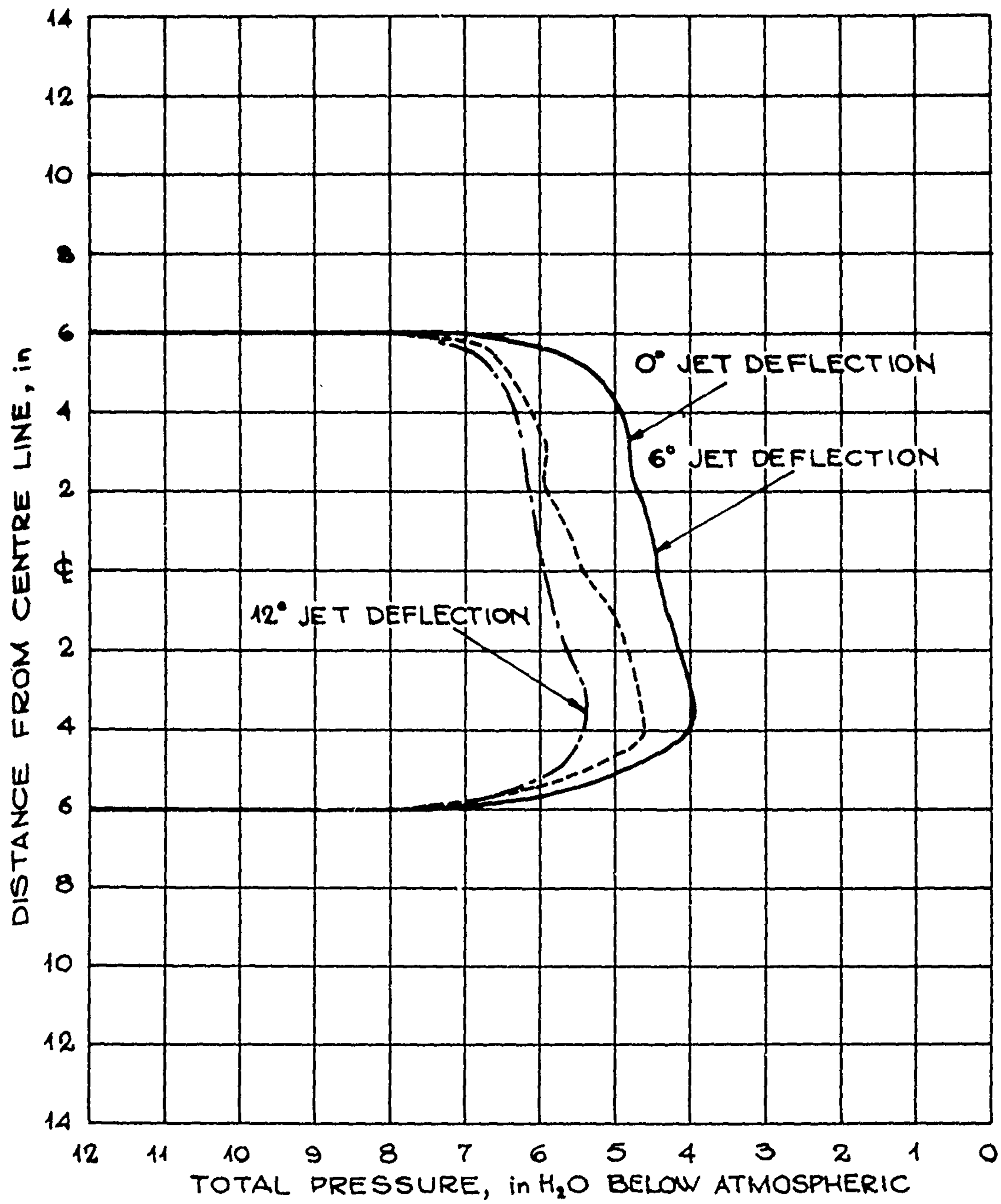
VERTICAL TRAVERSES AT 0° JET DEFLECTION
COLLECTOR NO. 21

FIG.12



VERTICAL TRAVERSES AT STATION 2
COLLECTOR NO. 21

FIG. 13



VERTICAL TRAVERSES AT STATION 4
COLLECTOR NO. 21

APPENDIX A

DESIRABLE BACKGROUND NOISE LEVELS

An important use envisaged for the facility is the study of the noise radiation of powered V/STOL aircraft models. An estimate of the acceptable background noise levels may therefore be based on the existing regulations for commercial aircraft. Current U.S. Federal certification noise levels are under review and may not be applicable to these special aircraft classes. However, in view of the lack of any officially recognized absolute levels for V/STOL aircraft, the standard of 95 PN dB at 500 ft arbitrarily adopted by de Havilland Aircraft appears to have received wide tentative acceptance. If one assumes a typical aircraft spectrum shape and the usual distance attenuation, this is readily converted to 82 dBA at 500 ft, or 89 dBA at 250 ft.

In the full scale facility, acoustic measurements would be made, typically, at 30 feet distance from the working section, corresponding to the reference microphone position used in the facility model. If one assumes a scale factor of ⅛ to 1/12 for the model in the working section, the 30 foot distance would scale to 240 to 360 ft in real life. Finally, if one allows for a 15 to 30 dBA improvement in the noise level requirements in the interval prior to full use of the facility, the expected requirements would then be about

62 to 67 dBA at 500 ft
≈65 to 70 dBA at 360 ft
≈69 to 74 dBA at 250 ft

Further assumptions concerning the typical source spectrum shape must be made in order to convert these estimates into a probable facility background noise requirement. If one assumes a broad band noise with a low frequency peak region not above 500 Hz, then the conversion to model scale will lead to an *increase* in the permissible A weighted level, since the reduction of noise level by A weighting is greater at full than at model scale. This increase would be considerable; up to 10 dBA may be expected for some low frequency sources. If, in the interest of conservatism, one ignores this point at this stage, and if the background noise is to be at least 10 dBA below that of the model under study, then the former should not exceed 55 to 60 dBA.

The desirable background spectrum shape appropriate to this level is more difficult to define, and again requires assumptions concerning the full scale noise sources. Because of this uncertainty, the above is a very loose specification at best. Generally, the full scale frequencies likely to be of interest lie in the 250 to 6000 Hz range, corresponding to about 2.5 to [illegible] kHz at model scale. Thus, the acoustic resolution of the facility is likely to be quite acceptable if the background spectrum falls off above 2 kHz with no objectionable high frequency peaks.

APPENDIX B

BACKGROUND NOISE DUE TO OPEN UNCOLLECTED JET

As an absolute floor level for the background noise levels at the measuring locations, the noise level of a free jet of length equal to that ahead of the collector can be estimated, ignoring the contribution of all collection noise sources. The following free jet calculations have therefore been carried out as a first order attempt to determine the absolute background floor level in the facility. It should be noted that since the calculations are based on free jet conditions they only approximate the radiation intensities to be expected in the open jet facility for the following reasons.

(i) A positive axial pressure gradient will be present in the confined jet flow. This will be more significant in the deflected jet, but will still be present in the undeflected case to provide for the required recirculating flow.

(ii) The recirculating and entrained flow will alter the mixing and shear noise sources from those encountered in a free jet.

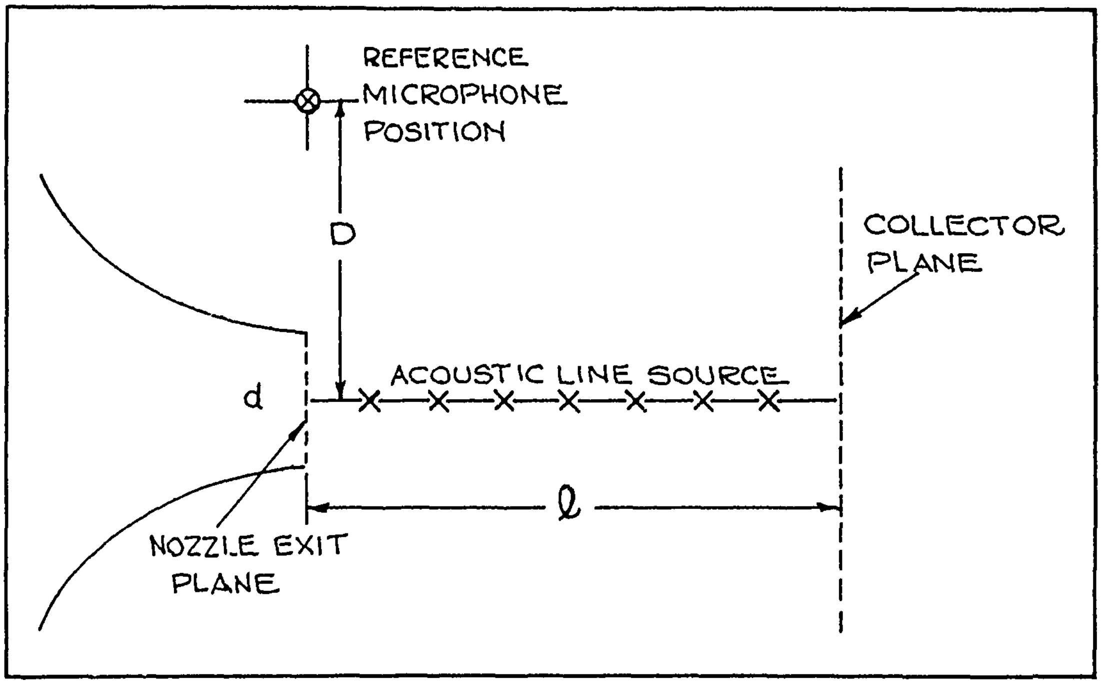
Assuming the jet noise sources to be adequately represented by a line source extending down the centre line of the air flow passage, straightforward cylindrical spreading calculations can be carried out to obtain the expected background levels at typical microphone locations. If one is interested only in the early portion of the jet mixing region, i.e. a jet length less than four diameters, it appears reasonable to assume a constant source strength per unit length throughout the entire source length.

Free jet radiation is known to be characterized by three distinct axial regions as follows:

(i) Mixing Region, $0 \leqslant X/D \leqslant 4$; source strength per unit length is constant, i.e. it varies as $(X/D)^0$.

(ii) Transition Region, $4 \leqslant X/D \leqslant 8$; variation of source strength per unit length is in transition between $(X/D)^0$ and $(X/D)^{-7}$.

(iii) Fully developed Jet Region, $X/D \geqslant 8$; source strength per unit length varies as $(X/D)^{-7}$.



Referring to the sketch above, the sound pressure level at the microphone location,

$$S.P.L._{(\text{ref. mic.})} = P.W.L. + 10 \log_{10} \frac{1}{4n\pi D\ell}$$

where $\quad P.W.L. = 10 \log_{10} \dfrac{W}{10^{-13}}$

W = total acoustic power of complete jet, w

D, ℓ = linear dimensions, ft

$D \approx$ 11 ft (full scale), or 11 in (model scale)
$\ell = 4.0$ D

l/n = the fraction of total jet power contained in the free jet length ℓ .

If n is taken as 2, then

$$S.P.L. \text{ (ref. mic.)} \approx P.W.L. \text{ (total free jet)} \; -25$$

The total acoustic power of the main jet flow is estimated to be 83 dB ±5 dB, using the conventional 8th power scaling for velocity. The rather high tolerance on the estimated power level reflects the low Mach number of the jet flow and the possibility that quadrupole noise may not dominate. Thus, the floor level of the background noise in the facility based on axial jet mixing sources only will be about 58 dB ±5 dB at the reference microphone.

These calculations could be extended to include the expected spectrum shapes appropriate to the truncated line jet source. Without carrying these out in detail, it is clear that the A weighted background floor level would be substantially lower. The A weighting adjustment to the above level is estimated to be of the order of 15 dB at model scale, or about 23 dB at full scale, so that A weighted values in the low forties would be expected as the ultimate background floor level for the model.